Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/GB05/000611

International filing date: 18 February 2005 (18.02.2005)

Document type: Certified copy of priority document

Document details: Country/Office: GB
Number: 0423500.8
Filing date: 22 October 2004 (22.10.2004)

Date of receipt at the International Bureau: 09 May 2005 (09.05.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed Behan

Dated 21 April 2005

Patents Form 1/77

Patents Act 1977
(Rule 16)

The Patent Office

THE PATENT OFFICE
J
22 OCT 2004
NEWPORT

1/77

25OCT04 E935700-1 C08642
P01/7700 0.00-0423500.8 NONE

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference — LA 1004

2. Patent application number *(The Patent Office will fill in this part)* — 0423500.8

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — NORMAN MATHESON LINDSAY, 19 BATCHELORS WAY, AMERSHAM, BUCKS. HP7 9AH

   Patents ADP number *(if you know it)* — 6297261002

   If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

   LAUNCH ANALYSER WITH REAL-TIME ADAPTIVE CORRECTION

5. Name of your agent *(if you have one)* — Graham F Coles.

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — Graham Coles & Co, 24 Seeleys Rd, Beaconsfield, Buckinghamshire, HP9 1SZ

   Patents ADP number *(if you know it)* — 4361556001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	24
Claim(s)	
Abstract	
Drawing(s)	9

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Norman M. Lindsay Date 21st OCT 2004

12. Name and daytime telephone number of person to contact in the United Kingdom NORMAN LINDSAY 01494 725000

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

LAUNCH ANALYSER WITH REAL-TIME ADAPTIVE CORRECTION

TECHNICAL FIELD

This invention relates to apparatus for measuring parameters relating to the motion of a moving article and, in particular, apparatus for measuring and recording the initial velocity and spin of a golf ball, predicting from the initial velocity and spin data the subsequent carry and flight duration of the ball, measuring the carry and duration of the actual flight and using the measured carry and flight duration data to correct the launch measurements and flight prediction model calibration parameters.

BACKGROUND ART

Most contemporary commercial ball launch analysers use time-elapsed photography to record and analyse the initial velocity and/or spin of a ball. One or more cameras capture images of the ball at two or more instances in time after initial launch and the velocity and spin of the ball are calculated from the relative positions and orientations of the ball images at two known instants in time.

The velocity and spin sensing method as outlined above has been established practice for many years. US Pat. No. 4.063,259 issued in 1977 is one early prior art document describing the use of a still camera with electronically controlled shutter and two or more electronically controlled flash lamps, the above being arranged to obtain images of a ball at two instants of time shortly after impact to provide measurements of ball speed, launch angle and spin rate. More recently, prior art such as US Pat. No. 6,390,934 issued in 2002, describes the use of digital cameras and image processing software to automate and enhance the measurement of ball launch conditions.

An indirect way of measuring the spin magnitude and spin axis of a golf ball is disclosed in GB Pat. No. 2334781, granted in 2002, where only the ball velocity vectors are measured and the ball spin vectors are deduced from measurement of the club head velocity, its position and its orientation at impact.

The measurements of a ball's launch velocity and spin vectors can be used to predict its ensuing flight carry and duration. However, the accuracy of such prediction is very prone to errors arising from inaccuracies in the flight model, inaccuracies in the launch measurements and variations in atmospheric conditions (e.g. wind speed, rain, temperature and pressure).

The present invention aims to provide improved methods of measuring ball launch parameters by additionally sensing the actual carry distance and deviation and the flight duration to correct the launch measurements and flight prediction model calibration parameters. Optionally, the position and/or timing of a ball's second impact (i.e. after bouncing off the ground) may be measured to determine the final direction, descent speed and other end-of-flight parameters.

According to a first aspect of the invention, there is provided apparatus for measuring parameters relating to the motion of a moving article, the apparatus comprising one or more light emitters for providing light from at least one reflector of known shape or pattern on the moving article and co-acting light sensors arranged to provide a signal when it is illuminated by said light, wherein at least one light emitter and co-acting light sensor subtend an angle of less than 5 degrees at the said reflector and common parts of the fields of view of the light emitter and co-acting light sensor define at least one detection plane across the path of the reflector and at least one of the light sensors is arranged to sense variations in the said signal when the reflector intercepts a given detection plane wherever the reflector intercepts the detection plane and light reflected by different parts of the said shape or pattern is detected as the reflector passes through the detection plane, the arrangement being such that the position and orientation of the detection plane relative to a reference frame is known and the time dependent displacement of the reflector normal to the detection plane and the orientation of the reflector about an axis within that detection plane can be determined from said signal.

According to a further aspect of the invention, the apparatus is provided in combination with one or more articles the movement of which is to be sensed, the, or each of the articles being provided with a retro-reflector and/or diffuse reflector. The reflector may comprise a single area of reflective surface with known shape, such as a triangle or rectangle or may comprise two or more separate

reflective surfaces in a known pattern such as circular dots arranged along a line, a barcode pattern or three dots on the corners of a triangle, and so on. The said retro-reflector is preferably, but not limited to, the corner-cube or prism type reflector and may be provided with special prism structures with biased and/or variable tilt axes in order to orientate the maximum reflectivity at an incidence angle other than 90 degrees and/or make the reflectivity more uniform over a range of incidence angles.

The article may comprise a golf ball and, according to a further aspect of the invention, there is provided a golf ball for use with the apparatus, the golf ball may be provided with at least one retro-reflector with the remainder of the golf ball surface providing a diffuse reflector.

The article may comprise a golf club and, according to a further aspect of the invention, there is provided a golf club for use with the apparatus, the golf club being provided with at least one retro-reflector preferably on the club head and/or on the lower end of the shaft, above the club head.

According to a further aspect of the invention, the apparatus is provided in combination with additional sensing means to detect and measure a golf ball landing position following a golf shot and data comprising the carry distance, deviation and duration of flight of golf shots are used to correct the ball launch calibration parameters and/or the ball flight model parameters, taking into account prevailing atmospheric conditions. The said sensing means may be optical, acoustic, electromagnetic, electro-mechanical, radio frequency or other means but in a preferred embodiment, the vibration created by the ball landing impact is detected by vibration sensing means and the position and time of impact is determined from signals generated in the said vibration sensing means. The vibration sensing means may be single devices, each attached to individual panels that vibrate on impact so as to indicate ball landing on the area of the panel and/or a distributed array of geophones to sense ground transmitted vibrations or the like. One preferred geophone arrangement uses buried piezoelectric cables near the perimeter of a sensing zone and/or arranged along grid lines distributed across the said sensing zone.

According to a further aspect of the invention, golf ball launch data (comprising impact time, launch velocity vectors and launch spin vectors), predicted carry duration data, predicted distance data, predicted deviation data, actual carry duration data, actual distance data and actual deviation data are used to identify the carry and deviation of each of several golf shots occurring in time and range proximity.

Preferably, one or more light emitters and co-acting light sensors subtend angles at the reflector of less than 2 degrees worst case, or more preferably less than 1 degree worst case, but typically 0.5 degrees or less. In this context, worst case means the maximum subtended angle corresponding to the minimum expected distance between the reflector and the apparatus. Preferably, the light emitters and co-acting light sensors operate in the infrared or near-infrared spectrum as this suppresses interference from extraneous daylight sources and is invisible to the user. However, other light wavelengths may be used.

For convenience, we adopt the following nomenclature:

'Detection plane' is abbreviated to DP;

The angle subtended at the reflector between a light emitter and its co-acting light sensor is the 'observation angle';

A light emitter and its co-acting light sensor is a 'TXRX pair';

The separation between the active elements in a TXRX pair (measured normal to the DP) is the 'TXRX separation'; and

The axis co-linear with the centre of the light emitter and the centre of the light sensor in a TXRX pair is the TXRX axis.

One means of creating a DP is to arrange the active elements in a TXRX pair in close proximity (e.g. 2 to 5 millimetres apart, but not limited to this range) and some distance behind a slit aperture. The width of the slit aperture may nominally equal the TXRX separation, with the length axis of the aperture perpendicular to the TXRX axis. Neglecting the finite size of the active areas in the TXRX pair and diffraction effects at the edges of the aperture, the width of the DP in this arrangement is nearly constant throughout the useful extent of the DP and is equal to the TXRX

separation (typically 3 to 4 millimetres). This controlled width DP is advantageously used in conjunction with retro-reflectors that have much greater reflective efficiency than diffuse reflectors, with the efficiency increasing with smaller observation angles. This increased efficiency helps to compensate for spreading losses at increasing range (and thus decreasing observation angle). When the DP is not more than x millimetres in width (where x can be any number, but typically 3 to 4 millimetres), different features in the shape or pattern of the reflector can be detected provided that these features are separated by at least x millimetres. By providing a line array of light emitters and light sensors with adjacent elements in the array forming a TXRX pair and with the array axis normal to the length axis of the slit aperture, the position of the DP can be altered, depending on which TXRX pair is selected or made active. In this arrangement, each TXRX axis is co-linear with the said array axis.

A second means of creating a DP is to arrange that the TXRX axis is parallel to the length axis of the slit aperture. Provided the TXRX separation is small compared to the length of the slit aperture, the fields of view for the light emitter and light sensor are nearly identical. The DP thus formed comprises the common field of view. An advantage of this type of DP compared to the previously described DP is that more light is emitted into the DP and more light is reflected back from the DP because the entire field of view is used. However, the width of the DP increases with range as it spreads out into a wedge shaped volume. This can be corrected using a cylindrical lens, so that the DP is again of uniform thickness (equal to the width of the slit aperture) or nearly so. This method of forming the DP improves its sensitivity and operating range.

It is sometimes desirable to use a diffuse reflector (e.g. one side of the surface of a golf ball). Because diffuse reflection is inefficient, the above second method of creating DP's is preferred for diffuse reflection. In this case it is sometimes advantageous to have larger TXRX separation (giving greater observation angles) to suppress retro-reflection relative to diffuse or spectral reflection from the golf ball or other object.

Means can be provided to enhance the detection of a retro-reflector in the presence of unwanted reflections from other parts of the moving article by placing a first light polarizing filter in front of the

FIGS. 3(a) and 3(b) are a plan view and a sectional side view of a short range target according to the invention;

FIGS. 4(a) and 4(b) are a plan view and a sectional side view of a first distance range target according to the invention;

FIGS. 5(a) and 5(b) are a plan view and a side section view of a second distance range target according to the invention;

FIG. 6(a) and 6(b) are schematic diagrams of a launch analyser apparatus according to the invention with a golf ball prior to impact;

FIG. 7(a) and 7(b) are schematic views of a detection plane arrangement according to the invention;

FIGS. 8(a) and 8(b) show a diagrammatic plan view and side view of a golf ball passing through detection planes; and

FIG. 9 shows time dependent waveforms representing sensor signals generated from detection planes in the arrangement of FIG. 8.

The block diagram of FIG. 1 outlines the top level system for a golf range facility according to one aspect of the invention where several golfers hit golf balls into the same general area. Blocks representing first, second and Nth golfers using the range are show at 1,2 and 3 respectively. The golfers launch golf balls downrange into the air of 'flight space' and onto the outfield at random times and with random distances and direction, and some of the balls land on instrumented target areas 4 where their landing position and landing time can be sensed. For the purpose of system analysis, the flight space has a transfer function with parameters comprising earth's gravity, air temperature & pressure, wind speed & direction and other factors that can affect ball flight such as rain or snow. We assume that the balls land on horizontal, flat terrain, but departures from this

that would significantly affect the carry of the ball can be built into the transfer function. Preferably, all the golf balls used in the facility are of similar external construction with nominally equal weight and diameter (which is true by default for all standard golf balls), and of closely similar impact and aerodynamic properties, which again is easily achieved.

Each golfer is provided with one launch analyser 5, 6 or 7 and balls are dispensed at or near the tee or at a central dispensing station. The launch analysers measure the initial velocity and spin vectors of the balls and from that predicts the landing co-ordinates and flight duration. The data from the launch analysers at each driving bay are transmitted to a central computer 8, which in turn relays measured data (if available) or otherwise predicted data on the outcome of each shot to the appropriate video display 9, 10, or 11.

The instrumented target areas may comprise only a small fraction of the total outfield area so a majority of balls may land in intermediate areas between the target areas. In these instances, the outcome of a golf shot is interpolated using computer prediction of the outcome based on accurately measured ball flight parameters.

The target areas measured data is used to apply corrections to the data generated in each of the launch analysers 5, 6 & 7 and to update the golf shot prediction model so that the interpolation of shot outcomes is accurate. The above corrections are generated using iterative algorithms that test where and how much correction is appropriate so after a few results from each launch analyser the predicted and actual data converge (to within very small tolerance). The correction process continues as long as golfers hit balls onto the instrumented target areas and adapts to environmental changes on an hour-to-hour and day-to-day basis. The computer can also monitor long term calibration drift in each launch analyser and elements in the ball landing sensors and apply appropriate correction or report that specific components of the facility require maintenance. Optionally, wind speed and direction can be measured by a monitor 12 positioned downrange and transmitted to the central computer to assist the prediction process. By this means the results shown on the video display units 9, 10 & 11 reliably report the correct results corresponding to each golfer's actual shots, and with great precision.

The launch analyser apparatus may be provided with a card reader to allow electronic payment for use of the facility. This may be a standard credit card or a special card issued by the driving range operating company. The special card would typically provide membership account data for an individual or group customer, such as membership expiry date (if required) and credit amount for future playing time. Additional data such as a customer's e-mail address can be used to relay the results of a practice or game session direct to the customer's home PC. Alternatively, data from individual customers could be automatically posted on a website and each customer provided with a unique password to allow private access to their results.

FIG. 2 is a diagrammatic plan view of the outfield, typical of a driving range according to the invention. The overall length and width of the outfield are 247 metres (270 yards) and 137 metres (150 yards) respectively, but the size and shape of the driving range outfield can vary significantly in different installations. In FIG. 2 the tee-off bays (not shown) are disposed along line 20. Five distance targets 21 to 25 are distributed beyond a barrier 26 and a plurality of short range targets 27 are disposed between the barrier 26 and the tee line 20.

The tee line 20 may be straight as frequently occurs in traditional driving ranges, but preferably it is curved as shown. This helps to partly equalise the average distances from any bay to each of the five distance targets 21 to 25 and also reduces the variation in aiming direction required from bay to bay. Thus arrows 28 indicate the straight ahead aiming directions for the two bay at the ends of the tee line 20. The centres of all the distance targets 21 to 25 are arranged to be within ±20 degrees of the direction of the arrows 28 and are also within ±20 degrees of the straight-ahead direction of all other bays. The sum of distances from any one bay to all the five distance targets average out to about the same total by virtue of the curvature of the tee line 20. Thus, each bay provides approximately the same degree of difficulty to successfully hit all targets. One short range targets 27 is provided for a small group of bays so that again the degree of difficulty to hit a short range target is approximately the same, irrespective of bay position. The arrangement thus ensures that game scores for players of equal ability are not significantly affected by bay position.

The barrier 26 is an optional feature, which may extend across the outfield or part thereof at about 40 to 50 metres or at other distances from the tee-off bays. It may be 0.5 to 1.0 metres high or higher and may comprise separate, spaced apart barriers. Its purpose is to provide a simple and easy test for beginners or very young players that also may form part of a points scoring game. For example, hitting the barrier 'on the fly' (i.e. without the ball rolling or bouncing before reaching the barrier) may score one point, whereas balls that carry over and beyond the barrier score two points. Distributed vibration sensors, for example a piezoelectric cable, built into the barrier or barriers sense when it is hit by a ball and the launch analysers confirm the bay from which any successful shot is made. The barrier thus provides a test of initial ability to at least hit a ball off the ground and carry some distance down a fairway, but ability to hit straight is not required. To add to the fun for junior players, the barrier may be provided with moveable targets such as large, imitation 'green bottles' or 'cartoon characters' sitting on top of the barrier, which provide additional targets that disappear from view when hit. These may be deployed only on special event days for children's parties or junior golf promotion, etc.

A second stage of ability is provided by the short range targets 27, which require some degree of both distance and direction control. These targets are typically set at 20 to 25 metres range and provide an attainable goal for the weakest players but also a facility for higher ability golfers to practice their short game with precise feedback. FIGS. 3 (a) and 3 (b) are a plan view and a sectional side view of a possible design for a short range target. The target 27 is typically circular in plan view, but may be otherwise shaped, and comprises a generally dome-shaped outer shell with a lid 30 and a skirt 31. The lid attaches to the skirt via a shock absorbent mounting 32 so that vibrations from impact on the skirt do not transmit readily to the top. The shell may be supported slightly above ground level by a shock absorbing mounting 33, which may extend along the full perimeter of the lower lip of the skirt 31. Balls landing directly on the outer shell 30, 31 create an impact noise that is above a pre-determined intensity level so the impact is detected by a microphone 34 inside the shell. The microphone 34 may be designed to reject far field noise and signal processing can be provided to distinguish between the sound of ball impact and other sounds such as wind, rain or thunder. A vibration sensor 35 attached to the lid 30 also senses impacts that land on the lid but not on the skirt and thus provides feedback to the central computer

to distinguish between impacts on the skirt and impacts on the lid. Once ball impact is detected, a processor 36 sends a signal to the central computer (8 in FIG. 1) to indicate a successful shot and record the precise time of the impact. Balls that roll along the ground towards the target 27, hit the shock absorbing mounting 33, but such impact generates insufficient sound intensity for detection. It may be preferable to provide some degree of dampening on the shell 30, 31 to limit the amount of rebound and/or impact sound intensity.

Typically, the overall diameter of the target 27 is 10% to 20% of its distance from the tee line 18 so as to provide a fairly easy target. The lid 30 typically has a diameter of only 20% to 50% of the overall target diameter and is thus much more difficult to hit directly with a golf shot. Optionally, the shell 30, 31 can be formed as one piece and a microphone used to detect impacts on any part of the shell (i.e. providing no distinction between impacts on the top part and the skirt). The slope of the skirt should not be steeper than 45 degrees on any part facing the bays, since otherwise there is a danger of a very hard hit, low trajectory ball rebounding back towards the bays. Optionally, the central top part may be provided with a layer of high friction and/or softer material so that balls landing with high backspin can be observed in the way they bounce upwards or backwards.

Preferably the ground surrounding a target 27 is fairly soft so that nearby missed shots do not rebound high off the ground and subsequently land on the target. However, in rare occasions that this does happen, the launch sensing and flight prediction system accurately distinguishes between direct hits and hits off a ground bounce so that such shots are not rewarded a game score. It should be noted that for very short distance shots (up to 30 metres or so) the ball flight is almost purely ballistic and not significantly affected by aerodynamic effects due to ball spin and/or wind. This is because the aerodynamic lift and drag forces on a ball are proportional to the square of its absolute velocity through the air. This being the case, extremely accurate predictions of landing positions and landing times are obtained from the flight prediction system for short, low velocity shots. These predictions can be calculated very quickly, so that the result is computed before the ball finishes its one to two second flight through the air.

To enhance the fun aspect of the driving range, visual and/or auditory feedback may be provided on the targets 27. For example, at least part of the shell may be fabricated from a translucent but impact resistant material and a high intensity lamp 37 inside the shell is switched on at the instant a validated shot hits the target. The light intensity can then be controlled to gradually dim, reducing to zero intensity over a few seconds, unless another ball hits the target in which case the transient light process is repeated. The light intensity can also be adjusted to be much greater during sunlight conditions compared to night-time or low daylight conditions. This provides a golfer with highly visible and instant feedback of success and in addition three points (say) can be added to his or her game score. Optionally, a message such as "3 POINTS!" can be reverse printed on the inside of the skirt in an opaque colour that matches the colour of the of the shell material, which, because the shell is translucent, is only visible to golfers as a dark symbol against an illuminated background when the internal lamp 37 is switched on. Various other lighting and colour effects can be provided. Additionally or alternatively, the sound of a ball impacting a short range target may provide auditory feedback and optionally this can be amplified and relayed to a speaker system local to the bay from which the ball was launched. This latter option can be arranged to more or less confine the auditory response to just the one appropriate bay.

FIG. 4(a) is a plan view of a distance target (i.e. any one of targets 21 to 25 in FIG. 2) of one embodiment according to the invention and FIG. 4(b) is a side view on section A-A of FIG. 4(a). Each target typically comprises three concentric, circular zones; namely a central zone, which is the area inside the dotted circle 40, an intermediate zone, which is the area between dotted circles 41 and 40, and an outer zone, which is the area between dotted circles 42 and 41. The target surface is simply the ground, which may be natural grass turf or synthetic turf and, in a first embodiment, there is no visible demarcation between the zones. Preferably, the overall diameters of the distance targets and the three zones therein vary in proportion to their distance from the tee line. For example, the outer diameters of the central, intermediate and outer zones may have diameters of 4%, 10% and 20% of distance, respectively. This rule is for guidance only and the intention is that the level of difficulty involved in hitting the targets should be roughly the same, irrespective of distance (given that a golfer has the ability to reach the most distant target).

This makes scoring consistent and fair, so all distance targets could, for example, have score values of 4, 6 and 10 points for the outer, intermediate and central zones respectively.

A pole mounted flag 43 marks the centre of the target and, surrounding the flag, there is a structure comprising a circular hoop 44 supported by slender struts 45 that hold the hoop above the ground at an inclination angle of (e.g.) 20 degrees so that the hoop is tilted upwards towards the tee line. The hoop 44 may alternatively be square with a diagonal aligned towards the tee line, or other shapes may be adopted. The struts are painted in camouflage colours to blend in with the background (as observed from the bays). The hoop diameter is slightly smaller than the central zone 40 and its purpose is to provide a clearly visible and distinctive object for the golfer to aim at, with an indication of the size of the central target. For a golfer, the hoop forms the 'Bull's Eye' of the target and any ball passing through or very close to the hoop impacts the central zone, inside dotted circle 40. To increase visibility, highly-coloured (such as fluorescent) bunting or the like may hang from the hoop and may, for example, be decorated with a sponsor's logo, etc.

Preferably, the hoop is provided with a retro-reflective surface so that it becomes highly visible in low ambient light conditions when it is illuminated by flood-lights mounted in proximity to each bay. The flood-lights may be fitted with Fresnel lenses or the like to optimise illumination of the outfield and the distance targets. Optionally, the retro-reflective surface may be shaped to ensure that the incident light from the flood-lights is always within a given maximum angle of incidence to ensure continuity of reflection on the sides of the hoop that are oblique to the observers in the bays. One means of achieving this is to have a corrugated shape as shown in the expanded view inset 46 of FIG. 4(a). Alternatively, individual retro-reflective elements may be mounted on the hoop to provide optimum night-time visibility at each bay. An environmental advantage of deploying retro-reflective lighting on the outfield is that the overall light power required is reduced and light infiltration outside the driving range is minimised. However, it may prove preferable to use high efficiency, coloured LED's as the technology for these devices is pushing performance boundaries year on year.

To facilitate turf maintenance and ball collection, the area of ground surface underneath a hoop structure 47 may be synthetic, alternatively the entire outfield may be provided with synthetic turf. Preferably, the area 47 is also slightly domed as shown in FIG. 4(b) so that balls landing on this area roll off and outside the hoop structure, beyond the struts, where they can easily be collected by a mechanised ball picker.

To detect the instance in time and the position of a ball landing on a target, five geophones 48 are buried under the target surface. The geophones are positioned at 72 degree angular intervals round the dotted circle 41 and they respond to vibrations caused by the impact of balls landing on the ground at or near the target. The relative times of an impact vibration arriving at each geophone allows accurate measurement of the landing position and instant of landing of golf balls that have carried the full distance from the tee line to the target. From this, the measurement system can accurately determine whether a ball has landed within the central zone, the intermediate zone, the outer zone or some distance outside the target. Preferably, the ground surface is conditioned to be fairly soft so as to absorb most of the energy of a ball on its first impact on the ground and thereby minimise the height of rebound. This in turn ensures that the geophones signals from a second impact after the first rebound are of much lower amplitude and can be rejected by signal processing. However, advanced processing might actually use second impacts to estimate the direction and steepness of descent of balls, so as to provide more information about the flight trajectories of each ball.

It can be seen from FIG. 2 that the distances between adjacent distance targets (i.e. between 21 and 22 or between 22 and 23, and so on) is large compared to the distances between geophones in each group of five. This in turn means that there is negligible cross-talk between signal sets. That is, a ball landing on or near a given distance target will generate strong geophone signals at that target but, due to spreading and transmission losses, impact vibrations from the same ball will be very severely attenuated at other target locations so other geophones in the system will not detect vibrations from balls landing at or near remote targets. With the configuration of five geophones as shown in FIG. 4(a), there is no spot near the target where the amplitudes of all five impact vibration signals can be expected to be of approximately equal amplitude, except for the

special case where the ball lands at or near the centre. Due to cylindrical and/or spherical spreading, the amplitude difference between minimum and maximum vibration intensities across all five geophones is greater than 6 dB for any impact on the target (except the said special case) assuming just cylindrical spreading and zero transmission losses. For the special case where a ball lands at or near the centre of the target, the impact signals are closely matched in amplitude but they are also almost synchronous, whereas off-centre impact signals are time-delayed relative to a first signal. For impacts occurring some distance away from the target, the vibration signals arriving at the five geophones are nearly matched in amplitude, are time-delayed relative to a first signal and also have very small amplitudes compared to local impact vibration signals. Means are provided to monitor the relative sensitivities of each geophone in an array throughout the life of the equipment, so it is not necessary to have tightly matched sensitivities as the system adapts to miss-match. It is therefore very easy to determine that a signal set emanates from an impact on the local target and not from a remote impact. Once a signal set is recognised as coming from an impact on or very close to the local target, the relative timings of the signals are analysed to determine the exact landing co-ordinates and landing time of the ball.

Other geophone array configurations may be adopted. The five-geophone array provides excellent rejection of far-field impact; provides means of monitoring sub-surface sound velocity along different propagation directions; and provides redundancy so that satisfactory measurement capability is maintained (using recent sound velocity data) in the event that one geophone fails.

Preferably, a local signal conditioning and processing unit (not shown) is provided at each target. This will analyse the raw geophones data, reject far-field impacts and compute the co-ordinates of the first (and optionally second) impact of balls landing within a given radius of the target centre. This processing unit will also communicate with the central computer (8 in FIG.1) and with any peripheral equipment such as a water jet solenoid. Power and communications lines may be provided by underground cables, but optionally cables will only be used to connect the target sub-system components and power for the sub-system, including radio communications to the central computer, can be supplied by rechargeable battery and/or a local solar power generator.

FIGS. 5(a) and 5(b) show a plan view and a side section view of a second distance range target according to the invention. Here, the ground forming the target is contoured. The central and intermediate zones form a dome or hillock 50 with preferably a uniform slope from top to bottom to ensure that balls are not able to come to rest on the hillock 50 but instead roll down and into a trench 51. The outer zone of the target is sloped into a conical dish 52 so that again balls do not rest but instead roll into the trench 51. The trench is itself sloped so that balls rolling into the trench continue to roll (from left to right in the diagram of FIG. 5(b)) and then down a drain pipe 53 and finally into a collection sump 54 from which they are periodically collected and returned to a washing and dispensing machine in the bay area. The floor of the trench 51 is preferably lined with a layer of low rolling friction material so that the balls roll easily down the trench and into the drain pipe 53, which has an internal surface with very low rolling friction. Similarly, the surface of the target is preferably artificial turf with low rolling friction. By this means, only small gradients are required to ensure that balls continue rolling from any part of the target and into the sump 54. However, it is also preferable that any area on which a ball might land (i.e. the target surface or the trench floor) should also have low rebound coefficient so that most of the ball's kinetic energy is absorbed on first impact on the target.

To enhance the visibility of the target, especially at night-time, the perimeter of the target is marked out with retro-reflective reflectors 55. These are arranged on an outer bank 56 with the reflectors nearest the golfers (on the left-hand side in the diagram) positioned near the bottom of the bank 56 and the reflectors furthest from the golfers on the top or even above the bank. Thus, a circle of reflectors is formed, which is slightly tilted up and towards the golfers so as to be in good view. A central flag and flag-pole 57 may also be retro-reflective.

Two separate, concentric piezoelectric cables 58 are buried a few centimetres below the target surface and adjacent to the perimeter circle of reflectors. These cables are connected to a differential amplifier (not shown) so that common mode noise (i.e. noise from distant sources such as road traffic, wind, etc.) is rejected and only vibrations caused by impacts close to the cables (e.g. golf ball landing impacts) are sensed. This arrangement detects very precisely whether a ball lands inside or outside the perimeter circle. A second set of piezoelectric cables 59 are arranged

in a grid formation covering the surface of the target inside the perimeter circle. In FIG. 5(a) we show eight such cables and each of the cables 59 are connected to one of eight amplifiers (not shown). The cables 59 are preferably buried somewhat deeper than cables 58 and detect signals of balls landing on any part of the target inside the perimeter circle to provide measurements of landing position and landing time.

Other designs of target, which may include traditional landscaped greens, bunkers and water features, etc., may be provided instead of, or in addition to, the distance targets described above.

For balls that carry further than 50 metres and onto the distance targets, a ball's spin rate and spin axis tilt at launch as well as its linear velocity vectors are critical to its eventual carry distance, carry deviation and flight duration. To reliably predict where and when a ball lands on the outfield so as to reliably match landing impact data with impact launch data, it is essential that the spin imparted on a ball at impact is measured as precisely as possible as well as launch angle and linear speed. This is especially the case at peak usage in large driving ranges when the likelihood of shots from different bays landing at nearly the same spot at the same time is most frequent. Ideally, the predicted shot outcomes (i.e. landing co-ordinates and landing time) and actual shot outcomes should match to accuracies that are equal or better than a golfer can be reasonably expected to observe. This would then ensure that the matching process works with complete integrity and credibility no matter how many balls land on any given target in any time slot. It is thus an aim of the invention to provide apparatus that measures ball launch velocity and spin vectors to a very high degree of precision.

For convenience, reference axes X, Y and Z are shown in the drawings. The Z-axis is vertical and points upwards. The Y-axis is horizontal and points downrange (i.e. along the general line of flight of a golf shot). The X-axis is orthogonal to Y and Z and points in the general `heel-to-toe` direction of a club head at ball address.

In FIGS. 6(a) and 6(b), a launch analyser 60 is positioned generally forward of the pre-impact position of a golf ball 61 and parallel but offset from the ball's expected straight-ahead launch

trajectory (shown by arrow 62). In practice, the launch trajectory will have elevation angle typically in the range 5 degrees (as in a low trajectory drive shot) to 30 degrees or more (as in a 9-iron shot) and may diverge from the straight-ahead direction by ±25 degrees or more in azimuth. The golf ball surface is provided with retro-reflective elements (RE's) 63 comprising small dots of retro-reflective material. A plurality of detection planes (DP's) emanate from upper slit apertures 64 and lower slit apertures 65. The DP's contain beams of light that are focussed into thin sheets that traverse the path of the ball 61 during part of its initial few centimetres of flight (e.g. from 10 to 50 centimetres or so). Dotted lines 66 indicate the vertical extent of one of the DP's emanating from an upper slit aperture, whereas dotted lines 67 indicate the vertical extent of one of the DP's emanating from a lower slit aperture. Along the horizontal and normal to the page, the abovementioned DP's are very thin with very small or zero divergence angles.

FIGS. 7(a) and 7(b) are more detailed views of a DP arrangement in FIGS. 6(a) and 6(b). A TXRX pair 70 comprises a light emitter device (LED) 71 and light sensor 72. A cylindrical lens 73 and a slit aperture 74 are arranged with the TXRX axis, the length axes of the lens, and the length axis of the slit aperture parallel and coplanar. The TXRX pair 70 is disposed on the principal focal line of the cylindrical lens such that parallel rays (show as dashed lines 75 in FIG. 7(a)) converge to a line focus on the TXRX axis. With this arrangement, the field of view of the sensor 72 and the irradiation field of the LED 71 coalesce to form a DP with nominally uniform thickness 76 equal to the width of the slit aperture and with angular extent 77 determined by the length of the slit aperture and the distance of the TXRX pair behind the aperture. The DP formed by the arrangement of FIGS. 7(a) and 7(b) is parallel to the Y = 0 plane, but in general the launch analyser apparatus requires other DP's that are rotated about the X and/or Z axes. In practice, it is difficult to ensure that the TXRX pair 70 is exactly placed on the principal focal line of the cylindrical lens 73. Small errors in positioning result in the DP either converging or diverging, so that the thickness reduces or increases slightly with increasing range. These variations can be accommodated in the data processing.

FIGS. 8(a) and 8(b) show a diagrammatic plan view and side view of a golf ball 80 in a first position **y1** just after impact and the same ball 80 in a second position **y2**, two milliseconds later

passing through DP's shown by dashed lines 84, 85, 86 and 87. The ball diameter is 42.7 millimetres and (purely for example) travels at 64 m/s so the distance between **y1** and **y2** is very nearly three ball diameters. The ball 80 has, by way of example, a regular octahedron dimple pattern and is provided with a spherically symmetric arrangement of eight RE's comprising two RE's 81 and 82 that are in most direct detection view of the lower slit apertures 65 and six other RE's 83, some of which are below the ball (FIG. 8(a)) or behind the ball (FIG. 8(b)). The RE's 81 through 83 are positioned on the centres of each facet of the octahedron. Note that the eight RE's thus form the corners of a hypothetical cube with sides 24.6 millimetres square and this provides a simple model of their relative spatial positions and orientations. Typically, each RE is inserted as a separate element within the area of one large dimple on the ball surface. The RE's may be small circular discs of micro-prism retro-reflective material, or may be single corner-cube prisms, 'cat's eye' lenses or the like. Alternatively, RE's may be directly fabricated or painted on the surface of a golf ball and individual areas may occupy more than one dimple. It is necessary that the means of attachment of the RE's onto the golf ball surface is robust and withstands the high impact forces and significant ball deformation during a golf shot. In one preferred construction the retro-reflective part has a tough, scratch resistant protective surface and is ruggedly attached onto a short cylindrical pellet that is inserted into cylindrical cavities formed in the ball during moulding. The depth of the pellet may extend beyond a thin outer casing (which is often about 2 millimetres thick in a 2-piece ball construction) and into the inner rubber core. Thus, the pellet is encased in a resilient and protective housing and may be prevented from dislodging by barbs on the pellet surface and/or adhesive bonding.

The RE's provide suitable reference marks from which the spin rate and spin axis as well as the linear velocity components of the ball can be detected. Advantageously, this arrangement can be used to measure the velocity and spin components of the ball with any arbitrary initial orientation prior to impact. Not only is the spin rate and spin axis orientation measured, but the orientation of the octahedron dimple pattern relative to the spin axis can be determined, which can provide superior characterisation in a ball flight prediction model. The spin and velocity measurement means may employ high speed, time-elapsed camera images, but preferably the measurement is

provided using an array of DP's. In alternative arrangements, six RE's may be positioned on the vertices of an octahedron pattern or twelve RE's on the facets of a dodecahedron and so on.

A significant advantage of providing a ball with retro-reflective parts on its surface is that it can be much more visible as it flies through the air during night-time or other periods of low ambient lighting. The higher visibility is provided by illumination from flood-lights mounted near each bay, which also illuminate the distance targets 21 to 25. As a ball flies down range, the observation angle (i.e. the angle subtended at the golf ball between the golfer's eyes and the local light source) gradually decreases, and consequently the reflectivity increases and partly compensates for the weaker illumination at greater range. The visibility can be increased by providing more of the ball's surface with retro-reflective surface. Preferably, each bay is fitted with a separate relatively low-power flood light positioned just above head-height but forward of the golfer so that there is ample head-room above and around the golfer to swing a driver or other club. This construction minimises the said observation angle, especially for balls with steep trajectories, and so enhances reflectivity off the ball. With this arrangement and judicious use of side-lighting and/or ground mounted lights, the total lighting power requirements can be significantly reduced compared to a driving range using standard golf balls and non-reflecting targets. This in turn minimises glare, sky glow and other light pollution problems as well as saving energy.

The ball passes through the four DP's 84, 85, 86 and 87, which all emanate from lower slit apertures 65 so the associated light sensors detect the reflections of associated light emissions off the side of the golf ball 80. Other DP's (not shown) emanate from upper slit apertures 64 and from other lower slit apertures. The DP's that emanate from upper slit apertures sense reflections from a different angle, directed downwards by typically 40 to 60 degrees. Also, DP's emanating from either upper or lower slit apertures (64 and/or 65) may be rotated about the Z-axis so as to be partly directed forwards or backwards along the Y-axis. Thus, as it passes through a plurality of DP's, the ball and the RE's thereon are detected from a multiplicity of angles and at various intervals along its initial trajectory so that plentiful data are available from which the ball's velocity and spin vectors van be accurately computed.

FIG. 9 shows the time dependant voltage signals **Va**, **Vb**, **Vc** and **Vd** corresponding to the golf ball 80 passing through DP's 84, 85, 86 and 87 respectively. The four voltage waveforms each contain two pulses 91, 92, of short duration and high amplitude which correspond to the passage of the two RE's 81 and 82 respectively through DP's 84 to 87. For simplicity, we ignore the presence of the other six RE's, some of which may be marginally within detection view. In addition to pulses 84 and 85, each waveform also shows a subsidiary pulse 93 of lower amplitude and longer duration coincident with both 91 and 92 and corresponding to the slower amplitude rise and fall of sensor signals as the ball enters and exits each DP in turn. By analysing the voltage signals we can find the four instances in time **t1**, **t2**, **t3** and **t4** when the ball passed through DP's 84, 85, 86 and 87 respectively.

DP's 84 and 86 are vertical and normal to the ball's azimuth direction. The ball velocity **Vy** parallel to the Y-axis is given by the distance between DP's 84 and 87 divided by (**t4** - **t1**). DP 85 is also vertical but is rotated about the Z-axis as shown. Consequently the displacement **δx** (see FIG. 8) is equal to **Vy** x (**t2** - **t1**) ÷ tan**θ**; where **θ** is the angle of inclination between DP's 84 and 85. Thus, the XY co-ordinates of the ball and the RE's can be found from analysis of the time delay between corresponding signals. Similarly, the ball's elevation angle is obtained from time delay (**t4** – **t3**), its speed and the geometry of DP's 86 and 87.

In the arrangement of FIG. 8 the reflector pattern repeats every 90 degrees so care is required to ensure that high spin rates are accurately recorded by providing suitable spacing between at least two DP's. Low elevation angle shots (i.e. drives) tend to have low spin rates whereas high elevation angle shots (i.e. pitching irons) have high spin rates; where spin rate is defined as the ratio of a ball's peripheral speed due to spin divided by its linear or translational velocity. Thus, it is advantageous to at least two DP's with small separation distance for high elevation angles and larger separation angle for low elevation angles and this is provided by DP's 86 and 87.

The qualitative features of the signal waveforms of FIG. 9 are evident, but it is not so obvious how to extract precise data from such waveforms. The preferred method is to use a guess of the ball and RE's motion and apply this to a mathematical model of the array of DP's and their response to

reflections off a ball and off those RE's that are detectible by the DP's. The main features of the waveforms allow an initial approximate guess of the ball velocity, trajectory and spin from which model data are generated. The model data and real data are compared and the differences are used to obtain an improved guess (i.e. an improved estimate). We repeat this process until the model data converges to nearly the same as the real data. The above is a simplified description of well-known techniques in engineering generally known as non-linear minimisation or non-linear estimation. One preferred mathematical technique for solving the estimation is the Levenberg-Marquardt method. In FIG. 9, the waveforms are shown as continuous traces, but in practice it is preferable that the TXRX pairs are operated in pulse-multiplexed mode and the data is acquired as a sequence of digital samples (from a sampling analogue-to-digital converter), which are then used as input data in a mathematical model of the DP's array and probable ball launch parameters. A non-linear estimation such as the Levenberg-Marquardt method then extracts accurate estimations of the true launch velocity and spin vectors of the ball.

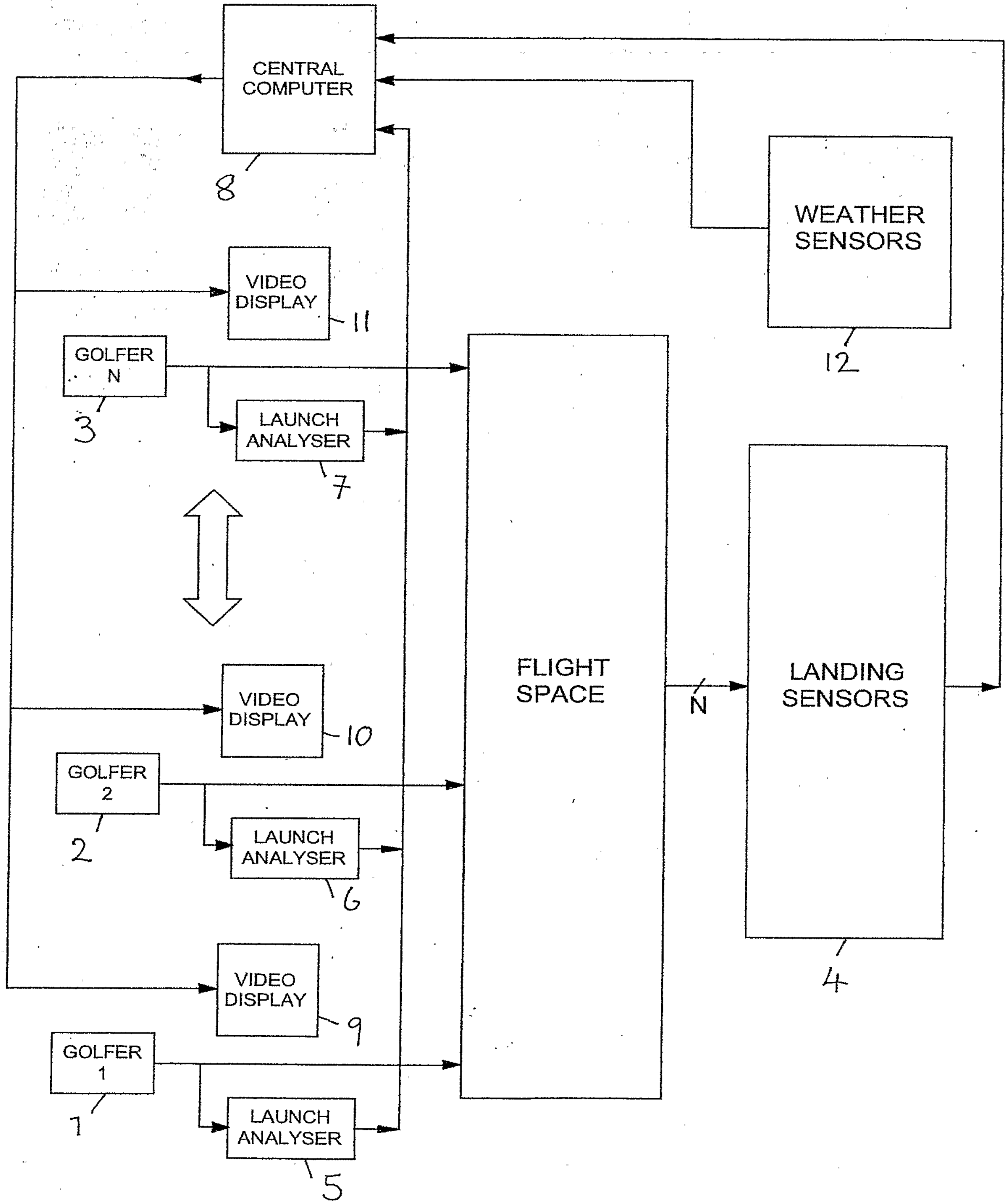

CENTRAL COMPUTER
8
WEATHER SENSORS
12
VIDEO DISPLAY
11
GOLFER N
3
LAUNCH ANALYSER
7
FLIGHT SPACE
N
LANDING SENSORS
4
VIDEO DISPLAY
10
GOLFER 2
2
LAUNCH ANALYSER
6
VIDEO DISPLAY
9
GOLFER 1
1
LAUNCH ANALYSER
5

FIG. 1

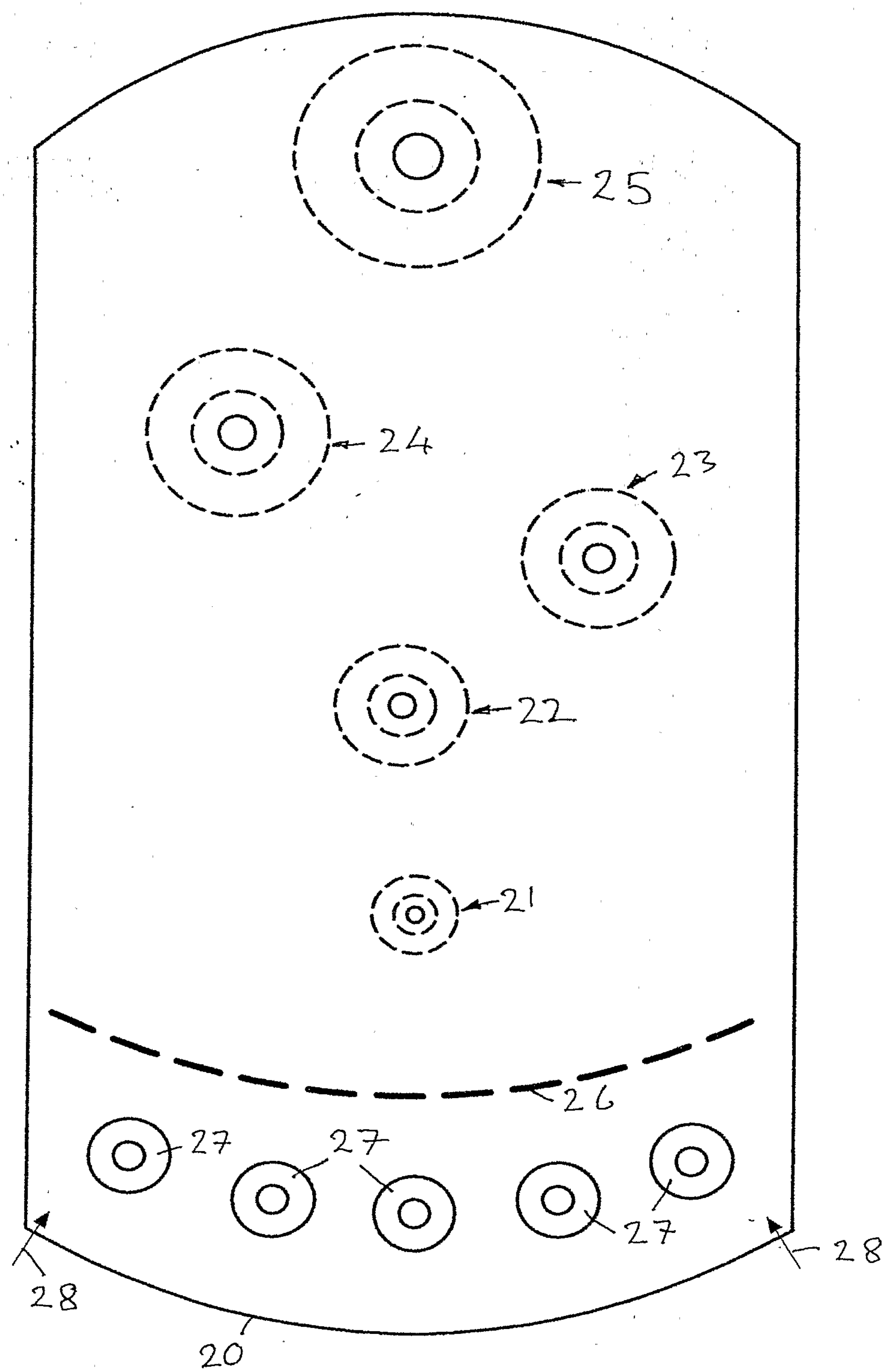
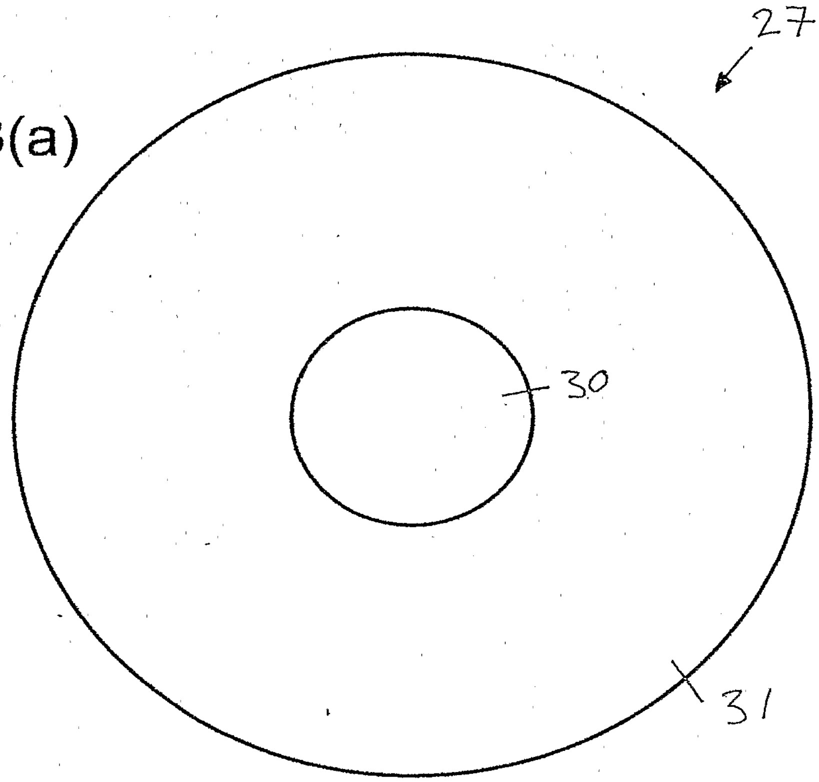


FIG. 2

FIG. 3(a)



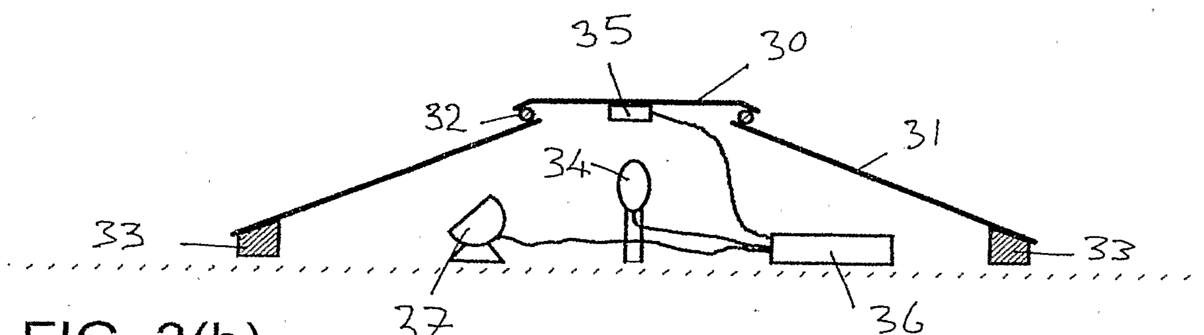


FIG. 3(b)

FIG. 4(a)

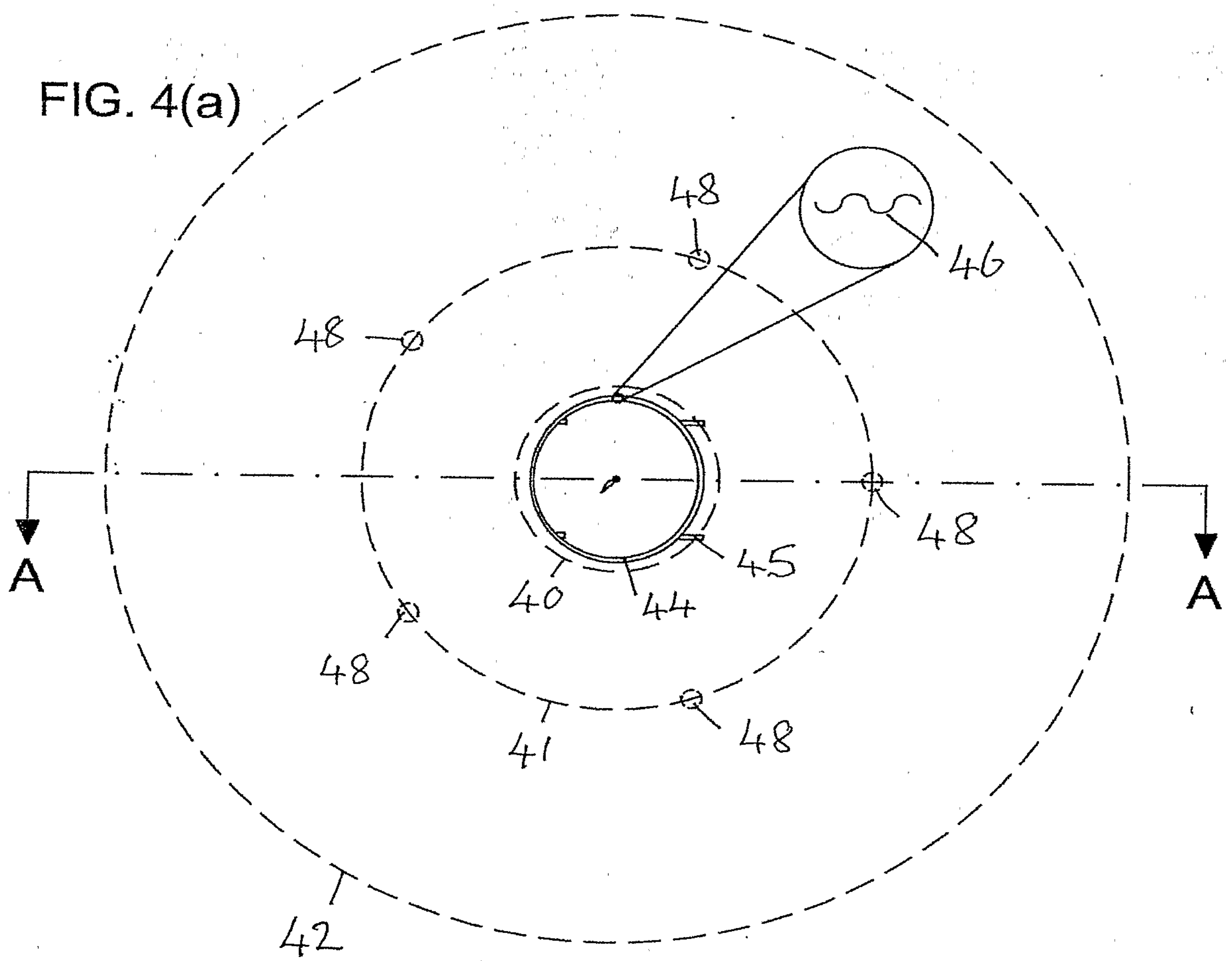


FIG. 4(b)

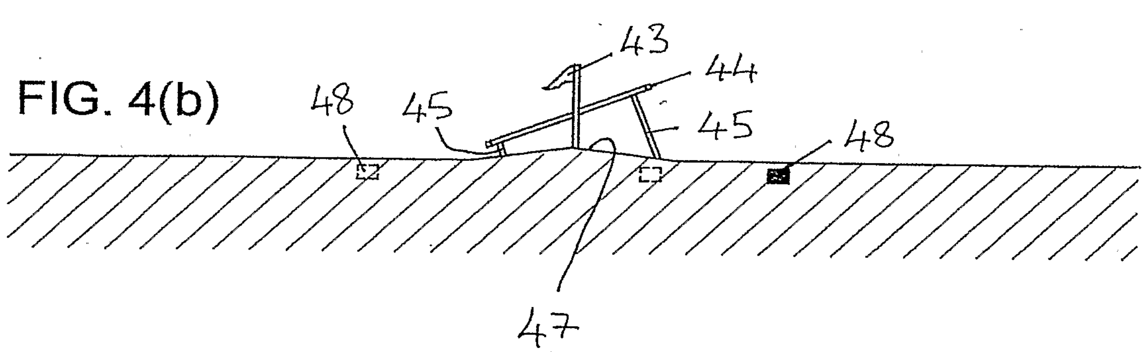


FIG. 5(a)

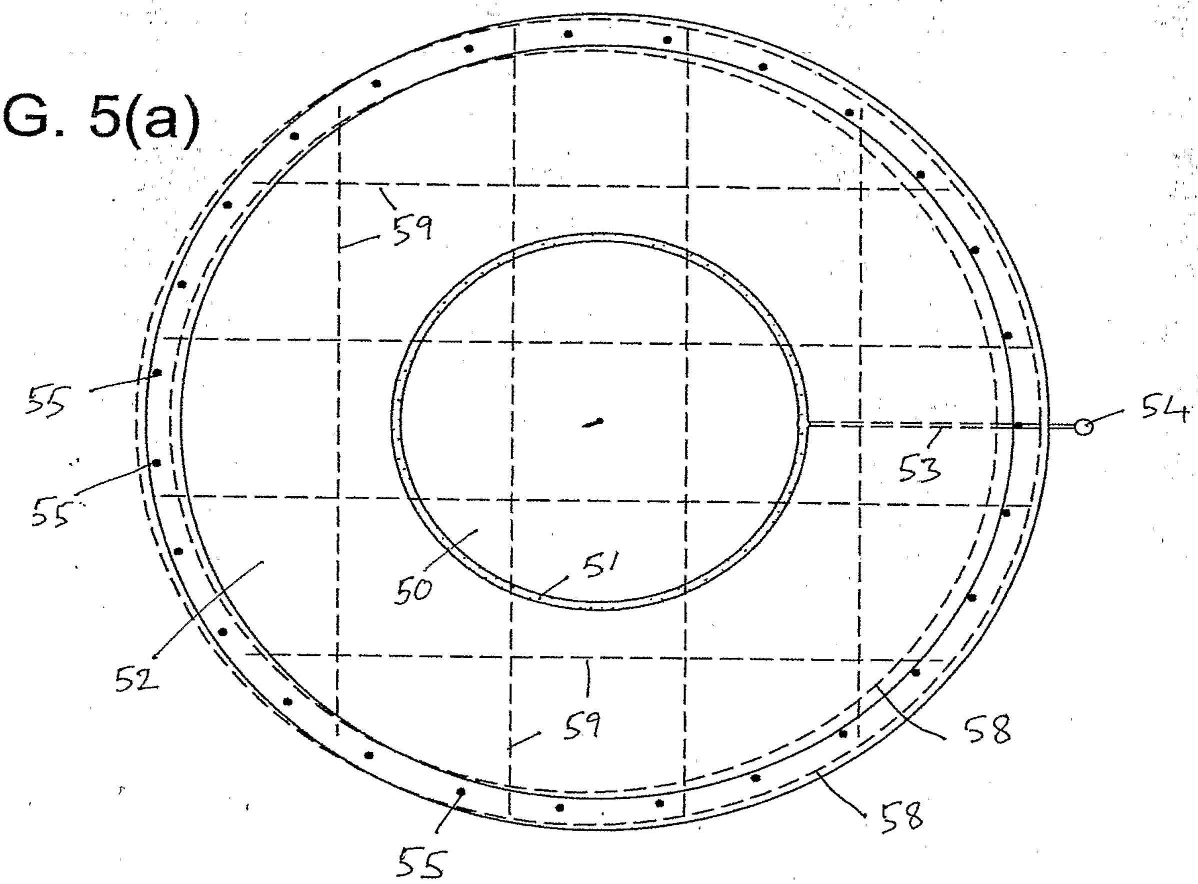
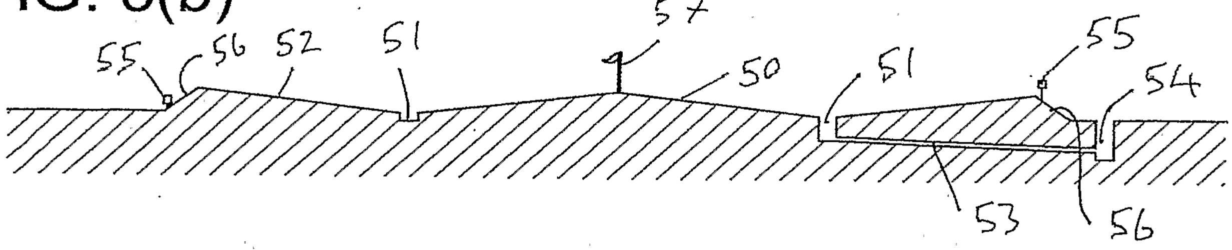


FIG. 5(b)



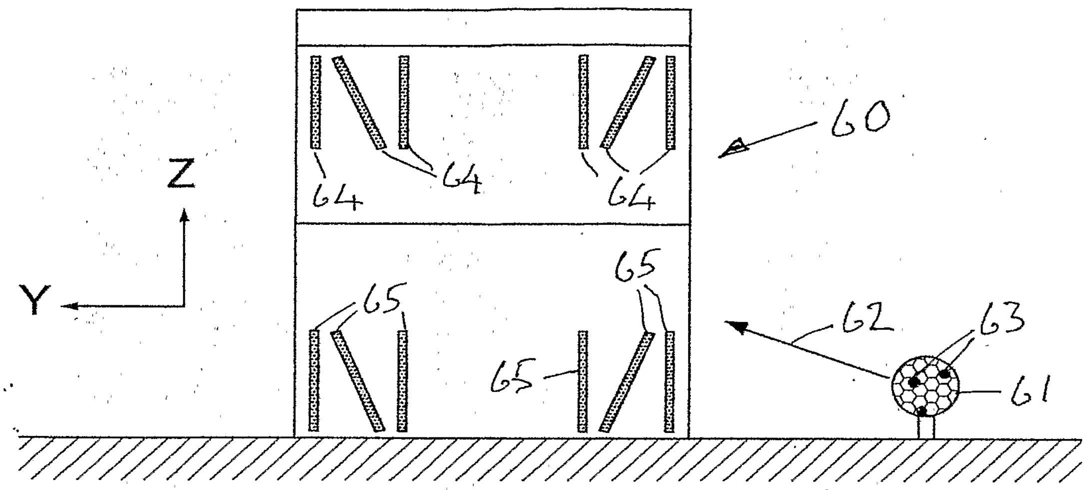


FIG. 6(a)

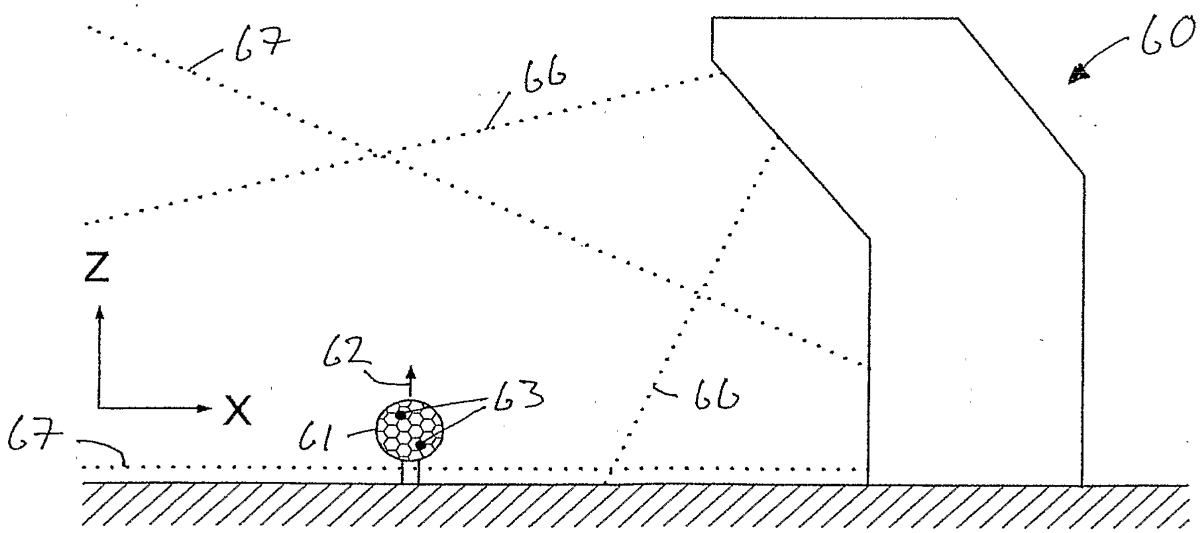


FIG. 6(b)

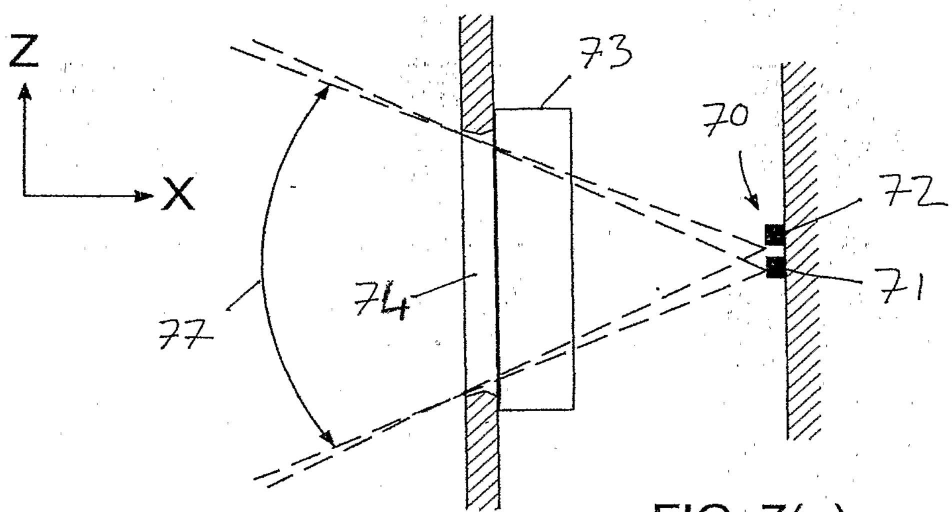


FIG. 7(a)

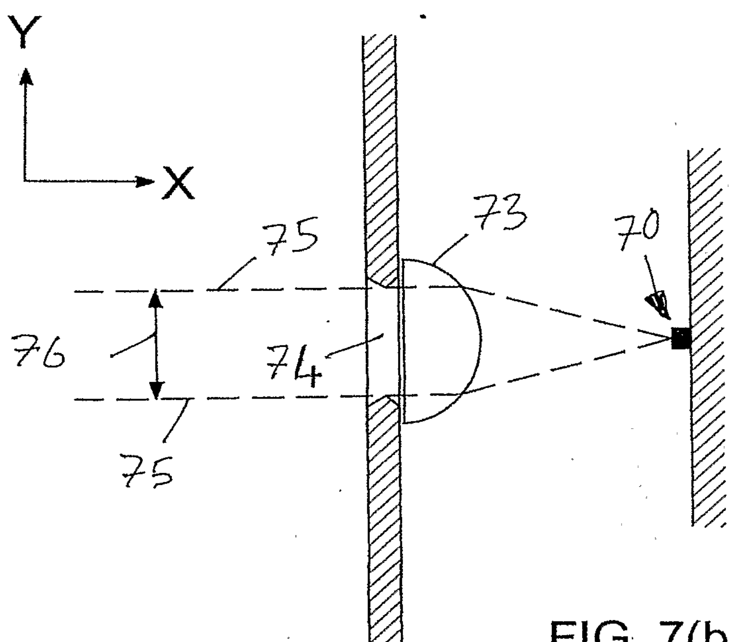


FIG. 7(b)

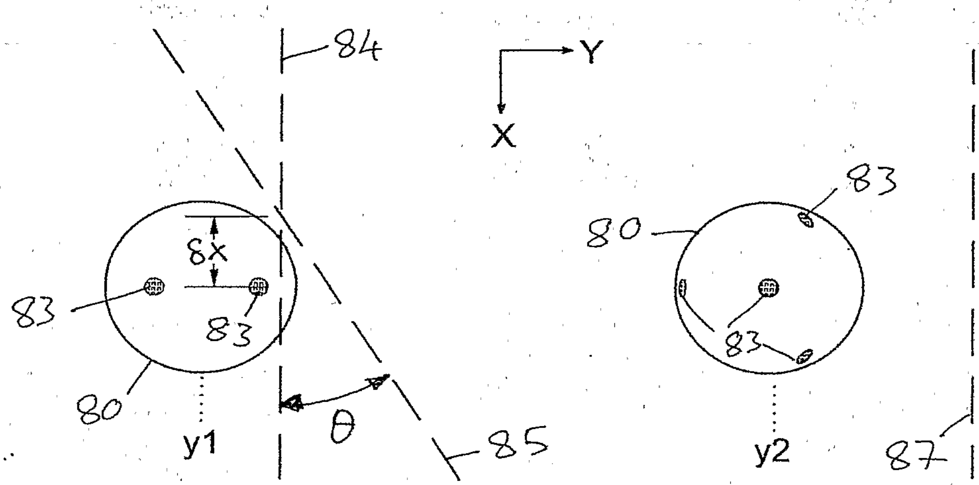


FIG. 8(a)

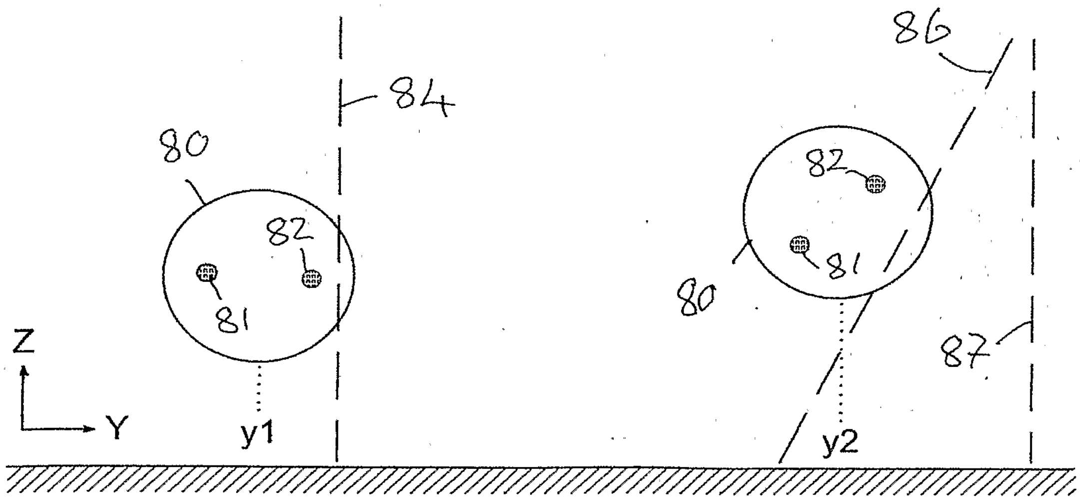


FIG. 8(b)

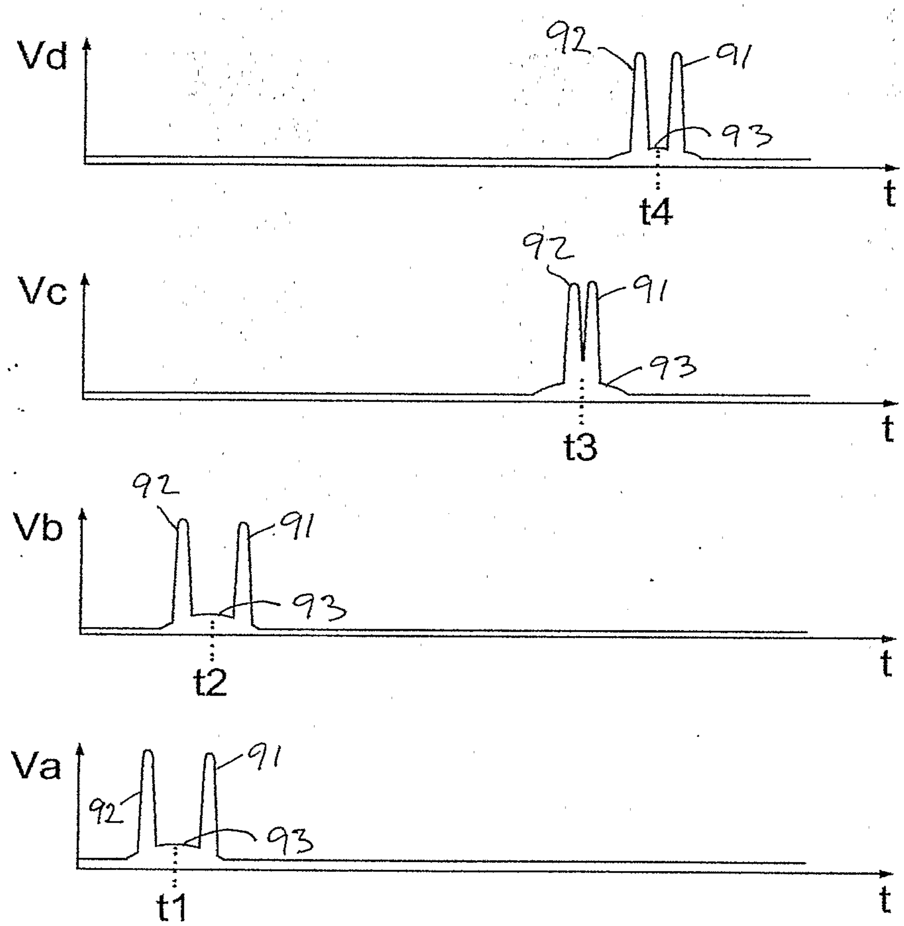


FIG. 9